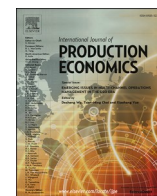




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New technologies in operations and supply chains: Implications for sustainability

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ABSTRACT

In this editorial piece, we first introduce the theme and objectives of the special issue on new technologies in operations and supply chains as well as their implications for sustainability. The papers comprising the special issue are then summarized, and major findings are briefly presented. Based on our observations on the submissions and the research gaps yet to be addressed, we attempt to offer our views on the directions for future research in the same research agenda, including discussion around research scope, research theory, research methodology, and research findings as well as in-depth studies concerning contemporary and imperative issues confronting operations and supply chain managers.

1. Introduction

In the production and operations management (POM) of today's manufacturing, there is an ever-increasing application of new technologies. The rapid development of artificial intelligence (AI), machine learning, new-generation data-driven information technologies, and new energy technologies for example, is surely unprecedented and has facilitated the advent of a 'new industrial revolution' (Dirican, 2015; Wuest et al., 2016; Li et al., 2017). In particular, the continuing integration of (increasingly) intelligent communication technologies with manufacturing can trigger the development of smart factories, intelligent manufacturing system architectures and intelligent manufacturing technology systems (Li et al., 2017). This new era of industrial transformation will undoubtedly bring about game-changing approaches, models, processes and systems in operations management, production planning and control, supply chain and logistics management.

We have seen a growing body of literature in recent years that have started to explore implications of these new technologies in manufacturing (Chen et al., 2012; Dirican, 2015; Wang et al., 2016; Wuest et al., 2016; Wamba et al., 2017; Koh et al., 2019). These initial studies have claimed that high-efficiency, high-quality, and cost-effective products and services for customers enhance the competitiveness of a manufacturing firm. This will be facilitated by the fusion and optimization of various stages of a manufacturing lifecycle

with new technologies (Wang et al., 2016; Zhong et al., 2016; Braganza et al., 2017; Gunasekaran et al., 2017). For instance, the adoption of autonomous-intelligent systems in developing automated machines that are clever, more effective and efficient to run (Pan, 2016), the utilization of the big data generated from the Internet of things (IoTs) in product design to enhance better customer experience (Nozaki et al., 2017), and the application of AI in optimizing logistics and supply networks (Wang et al., 2016; Zhang et al., 2017). It is obvious that these new technologies in manufacturing can create great opportunities for both new products/services and immense productivity improvement (Wuest et al., 2016; Kache; Seuring, 2017; Makridakis, 2017).

Yet while there has been much discussion about the impact of new technologies on such matters, there has been less coverage as to whether their applications could improve sustainability performance in the POM literature. This is despite the new technologies raising key questions. For example, the increasing application of digital technologies in operations and supply chain management is one of the major drivers of change. It stays open, whether the digital technologies will reduce the negative environmental impact, such as by avoiding certain products to be produced? For manufacturing firms, will the wide adoption of autonomous machines in factories lead to unwanted social impacts such as increased unemployment and greater wealth inequalities? Both on the environmental and social issues, this might be even harder to answer, as job gains and losses often occur in different parts of the supply chain, in

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many cases even in different countries. This interplay of information technology and sustainability thus deserves more attention from the POM research community. This creates a new arena for academics and practitioners to study and explain the degree of these far-reaching impacts, and potentially find solutions to addressing the three-pillars of sustainability as a result of adopting new technologies in manufacturing.

This special issue follows the notion that new technologies in manufacturing is a fast-growing and important topic in POM and that the research community has a vital role to play in work that builds sustainable operations in the new era of intelligent manufacturing. The main objective of calling this special issue was thus to provide a forum for scholars, practitioners and thought leaders to critically study, evaluate, explore and explain the new models, new ways, new means and new forms of intelligent manufacturing that create impacts on operations sustainability.

Based on the background presented above, we specified the thematic scope of the special issue with recommended topics that were particularly relevant to the special issue and its remit. These topics and their respective focuses are listed in Table 1 below.

Overall, the special issue was able to attract a total of 38 manuscript submissions, and 14 of which were selected after a thorough initial screening process and then sent out for double-blinded reviews. With the support of reviewers in their specialized field of expertise, eight papers have eventually been accepted for inclusion in this special issue. In the following section, we provide an overview of the accepted papers. In Section 3, we attempt to offer some guidelines and directions for future research pertaining to the special issue. Section 4 concludes the editorial.

2. Overview of the special issue papers

The papers comprising the special issue address the research theme of the initial call despite having their respective focuses from various

Table 1

Recommended topics in the special issue call for papers.

Topics	Main research focus
Studies on the impact of new models, new means and new forms of intelligent manufacturing on operations sustainability.	Impact of intelligent manufacturing on operations sustainability
Studies on intelligent manufacturing ecology, with the characteristics of ubiquitous network technology, cross-border integration, autonomous intelligent, product lifecycle intelligent design technology and mass innovation, etc.	Intelligent manufacturing ecology
Comparative studies on different types of new technologies in manufacturing and their impacts on operations sustainability.	Different types of new technologies
New technologies in manufacturing and their implications for sustainability in different cultural and regional contexts, including developing countries and SMEs.	Implications for different cultural and regional contexts
Impact of new technologies in manufacturing on various stages of a product lifecycle and its implications for sustainability.	Impact on different stages of a product lifecycle
Applications of new technologies in operations and supply chain management for environmental and social improvement.	Environmental and social improvement
New theory development to explain the implications of new technologies in manufacturing for sustainability at the firm, inter-firm, and supply network levels.	New theory development

angles. Table 2 lists the eight papers with the titles, authors, and main research focuses. They reflect a variety of new technologies in operations and supply chains, and their potential implications for sustainability. In brief, Afshari, Searcy and Jaber's work is primarily on additive manufacturing and eco-innovation drivers. Kouhizadeh, Saberi and Sarkis's paper focuses on blockchain technology and the barriers to its adoption. Li, Dai and Cui's research emphasizes digital technologies in Industry 4.0 and their impact on the economic and environmental dimensions of sustainability. Bai et al. provide a thorough evaluation of different Industry 4.0 technologies and their respective implications for different industries and the three pillars of sustainability. Shafiq, Ahmed and Mahmoodi's study focuses on supply chain analytics and pays particular attention to the social aspect of sustainability. Wang et al. introduce a new technology for optimizing perishable food production with quality, time, and environmental considerations, whereas Li and Epureanu and Liu et al. have their focuses on different stages of supply chains, i.e. modular fleet optimization and vehicle routing problems, respectively. In the following paragraphs, we introduce each of the special issue papers.

The paper by Afshari, Searcy and Jaber explores the role of eco-innovation drivers in promoting additive manufacturing (AM) in supply chains and offers a framework to examine how eco-innovation drivers could impact sustainable supply chains. To achieve their research objectives, the authors develop a mathematical optimization model to determine the optimal manufacturing process in simulated environments with a focus on drivers and an eco-innovation solution. The proposed framework is used to recommend the best location choices for establishing the desired supply chains with cost and pollution

Table 2

The eight papers included in the special issue.

Title	Authors	Main research focus
The Role of Eco-Innovation Drivers in Promoting Additive Manufacturing in Supply Chains	Afshari, Searcy and Jaber	Additive manufacturing; eco-innovation drivers
Blockchain Technology and the Sustainable Supply Chain: Theoretically Exploring Adoption Barriers	Kouhizadeh, Saberi and Sarkis	Blockchain technology; adoption barriers
The impact of digital technologies on economic and environmental performance in the context of Industry 4.0: A moderated mediation model	Li, Dai and Cui	Digital technologies; Industry 4.0; supply chain platforms; Chinese manufacturing context
Industry 4.0 Technologies Assessment: A Sustainability Perspective	Bai et al.	Industry 4.0; assessment of different I4.0 technologies
Impact of Supply Chain Analytics and Customer Pressure for Ethical Conduct on Socially Responsible Practices and Performance: An Exploratory Study	Shafiq, Ahmed and Mahmoodi	Supply chain analytics; social sustainability; U.S. manufacturing context
Coordinating quality, time, and carbon emissions in perishable food production: A new technology integrating GERT and the Bayesian approach	Wang et al.	Food quality and environmental sustainability; GERT and Bayesian approach
An Agent-based Approach to Optimizing Modular Vehicle Fleet Operation	Li and Epureanu	Modular fleet optimization; Agent-based modelling
Inventory Sharing Strategy and Optimization for Reusable Transport Items	Liu et al.	Vehicle routing problems; inventory sharing; reusable transport items;

analyses. Some of the key findings of their research include:

- Energy prices play a dominant role in driving the adoption of AM in supply chains.
- Market share is not a key driver that promotes AM adoption in supply chains.
- The processing and manufacturing times for AM technologies are longer than those for subtractive manufacturing (SM), and thus, AM could be facilitated by intense market competition and stringent regulations and standards to support the rights of end customers.
- At the current level of technology, “economies of scale” is applicable for SM while AM still needs technology improvement to benefit from it. However, in very small-scale markets, AM is more suitable for supply chains than SM considering the total cost, environmental impact, and customer satisfaction.

The authors conclude that the adoption of AM in supply chains is a strategic and long-term decision. However, moving towards AM-enabled supply chains will likely become mandatory rather than optional over time as new technologies offer the potential for improved customer satisfaction and customization of products and services. The proposed framework provides decision-makers with the key drivers to adopt AM in supply chains at minimum cost and environmental impact.

In their work, *Kouhizadeh, Saberi and Sarkis* theoretically study the barriers for adopting blockchain technology in supply chains for sustainability purposes. Blockchain technology includes several advantages such as that it can enable transparent, secure, decentralized ledgers, smart contracts and reliable networks for sustainable supply chain management (SSCM). However, the adoption rate has not been overwhelming. The authors first utilize the Force Field and TOE (i.e. technology, organization, and environment) theoretical lens to investigate a comprehensive set of barriers from the relevant literature, and then adopt Decision Making Trial and Evaluation Laboratory (DEMATEL) to explore the relationships and prominence of those barriers with inputs from academic and professional experts. Based on their study findings, the authors arrive at a list of theoretical propositions:

P1. Stakeholder theory can expand the usability and understanding of the TOE framework. Different stakeholders will perceive underlying factors differently, especially in emergent and complex technological and organizational relationships.

P2. Organizational barriers mediate the relationship between technological barriers and supply chain barriers in blockchain adoption for sustainable supply chain management.

P3. Blockchain and SSCM accessibility is reduced through maturity and security concerns within the technology TOE dimension. Lack of accessibility reduces blockchain in SSCM adoption.

P4. Blockchain adoption in supply chains requires tangible and intangible resources. However, intangible resources play a more important role in successful adoption.

P5. Blockchain adoption for sustainable supply chains will positively relate to relational rents and serve as motivation to decrease supply chain barriers. Relational rents are influenced by building sustainability-based relation-specific assets, improved knowledge sharing routines, building complementary sustainable supply chain resources, and embedding effective sustainability governance structures.

The research by *Li, Dai and Cui* investigates how digital technologies such as the Internet of Things (IoTs), cloud computing, and big data analytics might impact economic and environmental performance in the new era of Industry 4.0. The authors propose a moderated mediation model using digital supply chain platforms as the mediator and environmental dynamism as the moderator and tested the model using data from a survey of Chinese manufacturing firms. The results reveal that digital technologies can positively influence both economic and environmental performance. The adoption of digital technologies can facilitate the establishment of supply chain platforms in the context of industry 4.0. In addition, the mediating role of digital supply chain

platforms is confirmed in the test, which can be used to explain the relationship between digital technologies and sustainability performance. The authors argue that the effectiveness of digital technologies should be realized through the establishment of digital supply chain platforms. The study findings also reveal that environmental dynamism moderates the indirect effect of digital technologies for Industry 4.0 on economic and environmental performance through digital supply chain platforms. Based on the finding, the authors claim that, to realize better economic and environmental performance, manufacturing firms should not only rely on internal information processing capabilities gained through digital technologies, but also make the utmost digital supply chain platforms to access more information externally, especially in a dynamic environment.

In their paper, *Bai et al.* provide a thorough assessment of different Industry 4.0 technologies based on their sustainable performance and application. In order to achieve their study objectives, the authors propose a framework incorporating the United Nations Sustainable Development Goals and also develop a hybrid multi-situation decision method integrating hesitant fuzzy set, cumulative prospect theory and VIKOR. Then, they apply the method in a case study with data derived from a report of the World Economic Forum. The key findings include that mobile technology has the greatest impact on sustainability in all industries, whereas nanotechnology, mobile technology, simulation and drones have the highest impact on sustainability in the automotive, electronics, food & beverage, and textile-apparel-footwear industries, respectively. With respect to the three sustainability dimensions, blockchain and mobile technology seem to have the highest impact on the economic perspective; sensors and actuators followed by AI, big data analytics and cloud technology have the highest impact on the environmental sustainability dimension; whereas cloud technology and big data analytics seem to impact mostly the social sustainability dimension. According to their study results, the authors conclude that the sustainability impact of Industry 4.0 varies significantly with regard to specific technology, industry, and sustainability dimension considered.

The paper by *Shafiq, Ahmed and Mahmoodi* focuses on the social aspect of sustainability and explores the role of supply chain analytics capabilities and customer pressure for ethical conduct in the adoption of socially responsible practices by suppliers. To test their conceptual model, the authors administer a large-scale survey to purchasing and supply chain professionals in the U.S. manufacturing industry. Their results reveal that customer pressure for social responsibility can force suppliers to focus more on creating transparent supply chains as compared to employees' wellbeing. However, employee-focused social practices can have a better impact on firms' financial performance. As noted by the authors, this creates a dilemma and complexity in managing socially responsible supply chains as stakeholder demands are not always aligned with corporate goals. The authors claim that investing in analytics capabilities might help navigate some of this complexity, as analytics capability was found to be complementary to customer pressure for ethical conduct in adopting socially responsible practices. In addition, the results also suggest that supply chain analytics capability can lead to higher financial performance. The authors further posit that as the complexity of supply management increases, both analytics capabilities and the adoption of socially responsible practices are required. Based on stakeholder theory and the resource-based view (RBV), the study makes a contribution to the literature by investigating the link between supply chain analytics capability and the adoption of socially responsible practices by a firm.

In their paper, *Wang et al.* propose a new technology combining Graphic Evaluation and Review Technique (GERT) and Bayesian approach for quality improvement activities (QIAs) in perishable food production. The novel decision-making technology takes into account the trade-offs among three metrics of quality, time, and carbon emissions, and can handle both the dynamics and uncertainties of the three metrics resulting from the QIA decision making. The authors use bottled milk production as an example and further present a case study on a

well-known Chinese dairy manufacturing firm. Based on their study findings, they arrive at the conclusion that the proposed new technology can help 1) mitigate uncertainty but maintain the random nature of food production, 2) reinforce the stability of the probabilistic change of the three metrics by increasing of the QIA-trail size, 3) visualize the optimal trade-offs among the three metrics from different angles of view, and 4) figure out individualized sustainable quality management plans which are node-oriented and objective-oriented. This study highlights the advantage of implanting the Bayesian approach into the GERT for effective decision-making in food-production sustainability management.

The study by *Li and Epureanu* develops an agent-based approach to optimizing modular vehicle fleet operation. As noted by the authors, modularity facilitates assembly, disassembly, and the reconfiguration (ADR) of vehicles, which are beneficial in promoting fleet adaptability and life cycle cost savings. Given deterministic filed demands with operations stochasticity, the authors compare the performance of a modular fleet to a conventional fleet in equivalent operation strategies and also compare the fleet performance when driven by heuristic rules or optimization. Their findings suggest that fleet modularity can reduce the total resources supplied without significant loss of fleet readiness and that the benefits of fleet modularity can be amplified through a real-time optimized operations strategy. Based on their study findings, the authors recommend that for low-demand vehicles, high commonality is suggested to increase the pooling effect and reduce resource usage; whereas for high-demand vehicles, the design should reduce the ADR action time.

The research conducted by *Liu et al.* takes a unique angle by examining the use of reusable transport items (RTI) in packaging for creating economic, environmental and social benefits. Based on a case study of a leading RTI pooling company in China, the authors propose an inventory sharing strategy in the daily planning of distribution and the routing problem. A decision support framework is developed to optimize the firm's distribution and dispatching vehicle routes using a two-stage solution process. Their results indicate that the company can gain noticeable reductions in the transport costs and total travelled distance, which can bring about significant environmental and social advantages. Their research offers useful insights into the perspective of the RTI pooler as a sustainable solution to the increasing packaging wastes generated from the ever-growing globalized supply chains.

3. Directions for future research

These papers in our special issue make valuable contributions to the literature on the implications of various new technologies for sustainability in operations and supply chain management. It is clear that these new technologies are playing an increasingly important role in today's manufacturing, and their potential impact on sustainability should not be neglected. Based on our observations together with the knowledge advanced by the contributing papers, we attempt to offer some directions for future research at the intersection of digitization and sustainable operations and supply chain management:

First, regarding research scope, most existing research focuses on one or two technologies, and on certain stages of a supply chain. We believe that it could be interesting and potentially more useful to take a more holistic approach in addressing sustainability issues, for example, an emphasis on product lifecycle, Industry 4.0 ecology, new technologies for fostering business ecosystems, etc. Moreover, collaboration among manufacturing enterprises and information technology providers/platforms demands further in-depth studies. For example, whether and how data-centric digital platforms can facilitate sustainable supply chain management for manufacturing enterprises? For manufacturing enterprises, how to balance environmental, social and financial gains? For information technology providers/platforms, they may need significant investment for new technology development, but how much of such investment could and should be covered by benefited manufacturing

enterprises? In line with these questions, the sustainability effects of the new technologies stay rather open and should be explored further.

Second, looking at the theoretical foundations, the accepted papers have adopted different theoretical lenses in their research, including stakeholder theory, information processing theory, the RBV and TOE theories. These theories provide a solid foundation for developing the conceptual models, leading to interesting findings. In future studies, researchers are encouraged to adopt more useful and relevant theories in their research, either applying old theories in the new contexts or in an attempt to extend the existing ones. In this emerging era of Industry 4.0 and smart manufacturing, there could be chances to even explore and develop new theories that are particular useful for sustainability research, which is certainly worth considering. While full theories take a lot of time and effort to develop, conceptual framework combining different aspects and looking at the related causalities should be an intermediate step for such developments.

Third, regarding research methodology, we have seen that different methods have been adopted in prior research such as a survey that contains subjective measures and mathematical modelling with different scenarios. Only few researchers seem to have attempted to explore the real impact of new technologies through case study based analysis. We believe future research that uses the case study method could potentially offer useful insights into this research agenda, complementing other research methods. Game modelling can also be used to explore dynamic relationships between a manufacturing enterprise and a new technology provider/platform. Simulation may be also applied to examine environmental and economic gains under different scenarios using different new technologies. Yet, this is not a complete list of methods and it should rather not be seen as a complete list. It will be beneficial to employ a wide range of methods, thereby enhancing the diversity of approaches and contributing to future insights.

Fourth, regarding research findings, it seems that we have mainly focused on the pros of new technologies on sustainability in operations and supply chain but so far rarely addressed the cons of new technologies that they may bring along, especially from the social perspective. A simple example might be shifting production (back) to developed countries by employing 3D printing, thereby laying off staff members in low income countries. We argue that this overlooked arena certainly deserves more attention from the POM's community in addressing the future sustainability challenges. Moreover, investments (costs) and benefits may happen at the different stages of a supply chain. For example, if a component/part producer installs some new tracking technologies, the producer can benefit by tracking these components during product production and use, or even for management of the end-of-life product. This way, the parts might return for refurbishment or recycling, contributing to a circular economy. Related research questions are still open, such as: Would the digital technologies allow to overcome issues in tracking and tracing of products? What would the sustainability implications of such solutions be? Can it be implemented in an economical manner obeying environmental and social demands? How would the relationships among stakeholders along a supply chain to fairly cover cost and share benefits be coordinated?

Last but not least, as supply chains are getting longer and more complex, it becomes more challenging to manage the associated risks due to for instance natural disasters and geopolitical uncertainties. We have witnessed significant supply chain disruptions during crises, especially during the covid-19 pandemic, giving rise to supply shortages of essential items and humanitarian crisis in lots of places around the globe. Whether the new technologies have a critical role to play in mitigating the risks and combatting these crises? In addition, as organizations are using more and more advanced new technologies, can they develop better and stronger capabilities for responsiveness, resilience, and restoration of their operations and supply chains during and after disasters? Turning the argument on supply chain complexity around, this also triggers the question on whether shorter and more local supply chains would allow to manage environmental and social demands in a

sound manner and improving supply chain resilience. These can be very meaningful research questions to be addressed for future research agenda.

4. Conclusion

In this editorial, we have introduced the theme and aim of our special issue, and in particular, the eight papers that have been accepted for publication. These manuscripts offer useful insights for both academics and practitioners into the imperative sustainability research agenda. The findings from these papers make valuable contributions both in theory and practice by uncovering the implications of new technologies for sustainability in operations and supply chain management. Although these contributing papers focus on a good variety of relevant topics and perspectives, they are far from offering a whole picture of the entire research stream concerning the objectives of the special issue. Therefore, we have offered our views in pointing out future research directions, with a hope to simulate continued interests from the POM community to conduct meaningful and insightful research concerning new technologies and their implications for sustainability.

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